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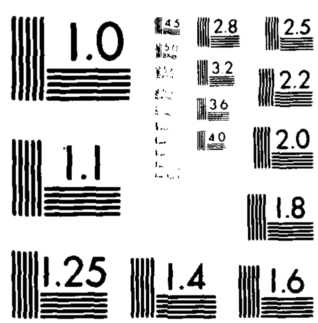

MICROCOPY RESOLUTION TEST CHART

A SOLID STATE DARK ADAPTOMETER.

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INTRODUCTION

Many of the current field exercises conducted within the Army involve extensive night maneuvers. Such exercises place large numbers of personnel and millions of dollars of sophisticated weaponry into a scenario. No accurate measurements have been made assessing the ability of these troops to adapt to low-level light or perform in night operations.

Recommendations have been made for the development and wide-spread use of a device to screen recruits and active duty military personnel for dark adaptation. It is estimated that perhaps as many as 15 percent of the "normal" population has some difficulty in altering light sensitivity in darkness. If the military has within its ranks a similar percentage of adaptation problems, there may be a platoon sargeant, company commander, tank commander, or others in a night exercise with minimum ability to adapt to the low-level light environment. Without actual intent, this individual may jeopardize the lives of other military and destroy friendly lives and equipment because either the individual cannot adapt or has not realized that adaptation is a problem.

The subjective phenomenon of dark adaptation is familiar to us as the initial inability to "see" when entering a dark room from a bright-light environment. The longer we stay in the darkness the better we can see. The sensitivity of the fully dark-adapted human eye is unsurpassed by even the most sensitive physical detection systems. The functional relationship that describes this increase

in sensitivity with reduction in ambient light levels is known as dark adaptation. Our purpose in this paper is to show how the military can improve the measurement of dark adaptation in its personnel.

The quantitative measurement of this process has traditionally been a complex problem. The technique involves various light sources, filters, optics, and graphic data reduction. A two-step procedure is always involved. The visual system must brought to a standard level of light adaptation and then, subsequently, the temporal course of visual threshold in the dark-adapting eye can then be measured over a subsequent 20 to 30 minutes of darkness. The typical function measured in this manner for a large retinal area with an unfiltered white light test source passes through an initial plateau at about five minutes ("rod-cone break") before achieving a final plateau 20 to 30 minutes after the termination of light adaptation. The initial portion of dark adaptation measured in this manner is attributed to the dominance of cone function over rod function during the early minutes of dark adaptation. (The cone system is the human photoreceptor system that mediates color vision and visual acuity. The human rod photoreceptor system mediates absolute visual sensitivity.) The final dark-adapted threshold, occurring 20 to 30 minutes after light adaptation, reflects the dominance of rod vision and the ability of the rods to detect minimal light levels.

While conventional dark adaptometry has traditionally employed a white light test stimulus and relatively intense light adaptation exposure levels, other approaches to the separation of rod and cone dark adaptation processes are possible. If dark adaptation functions are measured with spectral (monochromatic) rather than white light test sources, functions varying in steepness and rate of adaptation are obtained as a function of spectral (monochromatic) location (1,2). Functions measured with red light are generally more shallow and rapid in adaptation. They appear much like functions measured for central retinal regions that are dominated by cone photoreceptors (3). Functions measured with green or blue-green lights are steeper and require more time for full adaptation. Such functions are more of a composite of both rod and cone processes. By appropriate selection of test light wavelengths and retinal location, such functions can be made to reflect specific local retinal receptor processes.

Until recently, the measurement of spectral dark adaptation functions of any kind has been even more complex than conventional measurement of dark adaptation with white light sources. The

development of light emitting diodes (LED) that emit selectively in the long (red) and in the intermediate (green) spectral regions has changed this situation. In this paper, we will introduce a new solid-state dark adaptometer recently developed at the Letterman Army Institute of Research (LAIR) that uses red and green LED sources to separate rod and cone function in a rapid and a simple automated technique for spectral dark adaptometry (4).

METHODS

A schematic illustration of the LAIR dark adaptometer — its principle of operation, pulse modulation; and its product, a sample individual dark adaptation function — is presented in Figure 1. A 36-inch hemisphere, fitted with a chin and headrest, can be indirectly illuminated to provide a constant uniform light adaptation source of 110 candela/m^2.

Red and green LED sources are mounted inside the hemisphere and are used in either of two display modes. In Display 1, five blocks of LED red and green sources are mounted on a board. At their widest points, they subtend an angle of 20 degrees at the retina (Figure 1). This diode array was specifically designed to test a large area of the retina without the use of any specific fixation point. The subject is simply instructed to respond when <u>any</u> test light is just visible. In Display 2, specific fixation to a central fixation diode is required. Any retinal area over an eight-degree region of the retina can be <u>focalized</u> by this arrangement and local spectral dark adaptation of this retinal region measured. If the proximal ring of diodes is chosen, the dark adaptation measurement will reflect adaptation primarily in the central retina (foveomacular dark adaptation). If the outermost ring of diodes is chosen at eight degrees from fixation, then a peripheral retinal dark adaptation function will be obtained. The display contains two complete "crosses," one comprised of red and the other comprised of green LED sources. Each display is a separate modular unit. Changing modules from one to the other involves plugging in the appropriate diode display board into the same control socket.

Visual threshold measurement in this apparatus was made by a pulse modulation procedure where pulse width varied from one to 10,000 μsec (duty cycle) at a pulse repetition frequency of 100 Hz, a value above fusion flicker threshold. In this pulse domain, average quantal flux rather than average power determines threshold level. Thus, for a constant output power of the LED, the total average quantal flux required for threshold is directly manipulated

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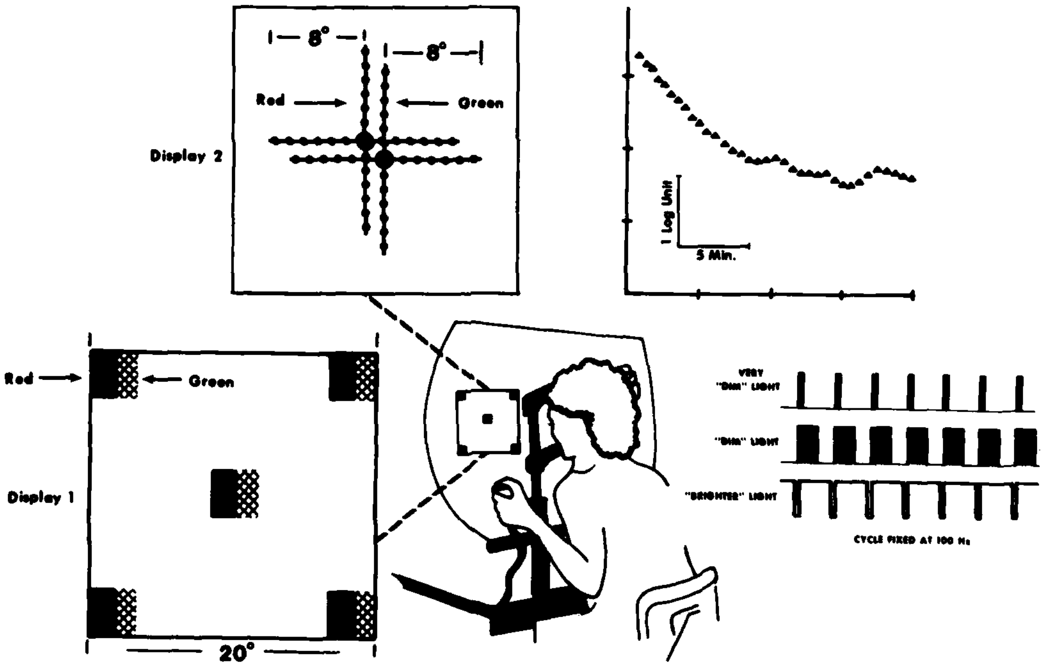

Figure 1. A schematic illustration of the LAIR dark adaptometer with interchangeable display modules. In the upper right, a sample dark adaptation function as drawn under computer software control by the X-Y plotter is shown. The duty cycle or pulse width modulation for a dim light (late dark adaptation) as compared to that of a bright light (early dark adaptation) is shown in the lower right insert. Threshold pulse width decreases as dark adaptation increases.

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by pulse width variation. (In independent experiments, the reciprocity between diode output power, i.e., light output, and pulse width modulation was unity over the pulse width range from one to 10,000 microseconds.)

The LAIR dark adaptometer is controlled by a low-cost microcomputer system and the function shown in Figure 1 is an on-line sample of the final output of this system. This computer system automatically calculates threshold pulse widths and prints them out as the subject is being tested. Presentation of different spectral LED sources is alternated and independent estimates of thresholds are calculated and alternately printed. The digital records of the threshold estimates of each subject are labeled and stored on a magnetic disk for later review or statistical analysis. An X-Y plotter provides the on-line copy of each dark adaptation function obtained for both spectral sources. When Display 2 is used, the computer operates the fixation LED and automatically adjusts its level to be a fixed constant pulse width increment above the threshold pulse width that is continuously being estimated by the computer.

For the data presented in this paper, the following protocol options were used. Light adaptation for five minutes at a hemispheric illumination level of 110 candela/m^2 was given to each subject before 20 minutes of darkness. During this time threshold estimates were continuously made for both spectral light sources. While computer software provided two options for the psychophysical test procedure, tracking and ascending limits, only the tracking procedure was used in the experiments reported in this paper. In the tracking procedure, the subject was required to depress the response button whenever a light was detected and not to release this button until the light was no longer detectable. Thresholds for both red and green LED sources were continuously tracked over the 20 minutes of darkness in this manner. When a fixation source was employed, the subject was carefully instructed not to depress the response button until light other than the fixation source was detectable. The computer automatically signaled the end of the test by displaying all of the LED sources at level above detection threshold for the dark-adapted eye.

A total of 21 human volunteers (average age 25; 3 women and 18 men) were tested. One of these volunteers was a referred patient (man, age 23 years); one was the human protanope (man, age 50 years).

RESULTS

Dark adaptation functions measured for 19 human volunteers for both the red and green LED sources are shown in Figure 2. These data were obtained by using LED Display 1 where thresholds were measured without fixation over a nonspecified 20 degree retinal area. Average threshold values were calculated at 1.25 minute intervals over the 20 minute dark adaptation period for both the red and green LED sources. The inner horizontal bars about each threshold point represent ±1 standard deviation, whereas the outer horizontal bars about each threshold point represent ±2 standard deviations about each mean threshold point. The variability of the curves is approximately ±0.5 log units over the entire 20 minute range of dark adaptation. The green LED function is slightly more variable at five minutes than at other times during the dark. (This variability may reflect individual differences in the rod/cone break of the dark adaptation function.)

The basic shapes of these functions are not similar. The dark adaptation function for the green LED covers nearly a two log unit range as compared to less than a log unit range for the red LED function. Dark adaptation is more rapid for the red LED source than it is for the green LED source. (This also reflects the possible operation of more than one photoreceptor system measured with the green LED.)

Data from a single volunteer are presented for comparison with the normal data (Figure 2). On the green LED for this subject, data points fall more than three standard deviations above normal values throughout most of the dark adaptation period. While he was closer to the norm for red LED function, his data were still more than 0.5 log units higher than threshold throughout the dark adaptation period. This subject was diagnosed as an individual with peripheral retinal disease; he had complained of his lack of being able to see at night. His vision under daylight condition was within normal limits as measured on standard tests of spatial vision (5).

Dark adaptation functions measured (Display 2) at three eccentricities from fixation are presented for one representative normal human subject (Figure 3). From this figure, one can compare the measurements at one degree eccentricity between the normal human volunteer and a human protanope (a person who has difficulty in making color discriminations in the red region of the visible spectrum). At an eccentricity of eight degrees, the red and green LED sources yield dark adaptation functions similar to those shown in Figure 2. However, as eccentricity from fixation is made more

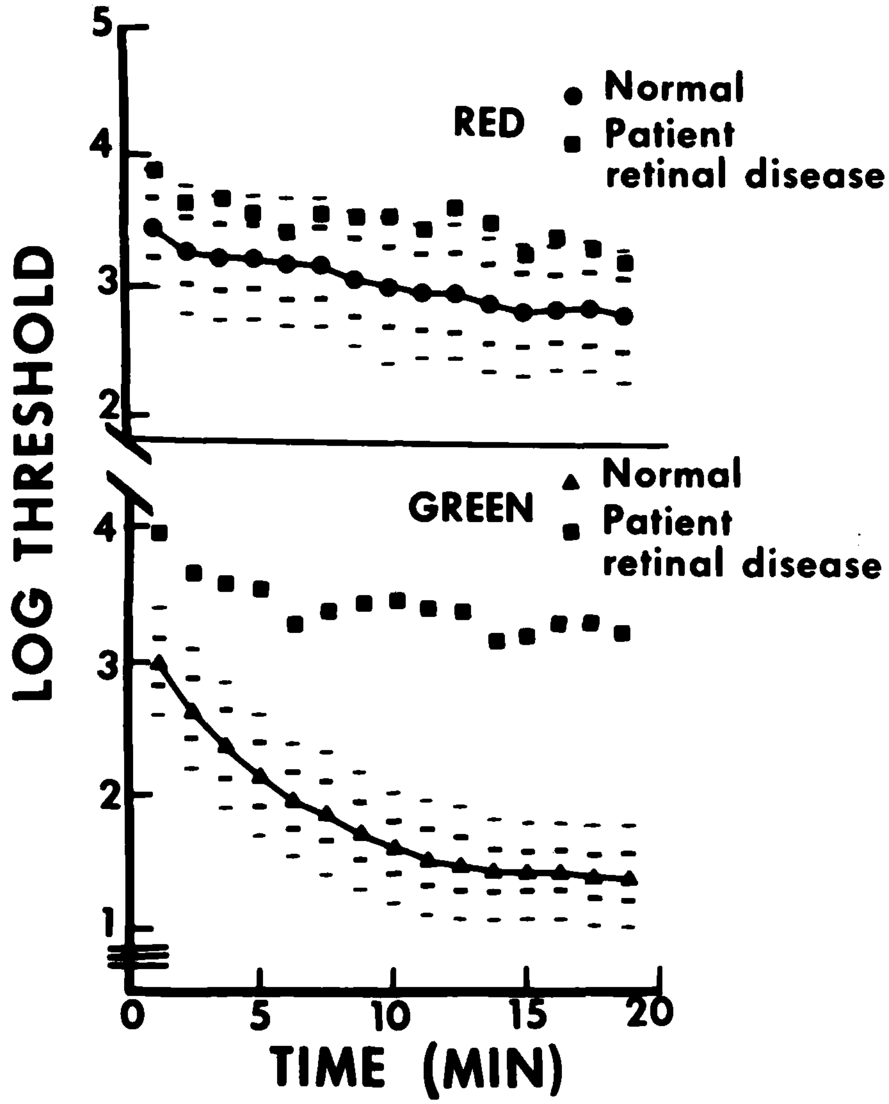

Figure 2. Average data from 19 human volunteers shown for both the red and green LED measured with Display 1. The inner horizontal bars represent ±1 standard deviation and the outer bars represent ±2 standard deviations about each mean threshold. Data from one volunteer patient with peripheral retinal disease are presented for both LED sources.

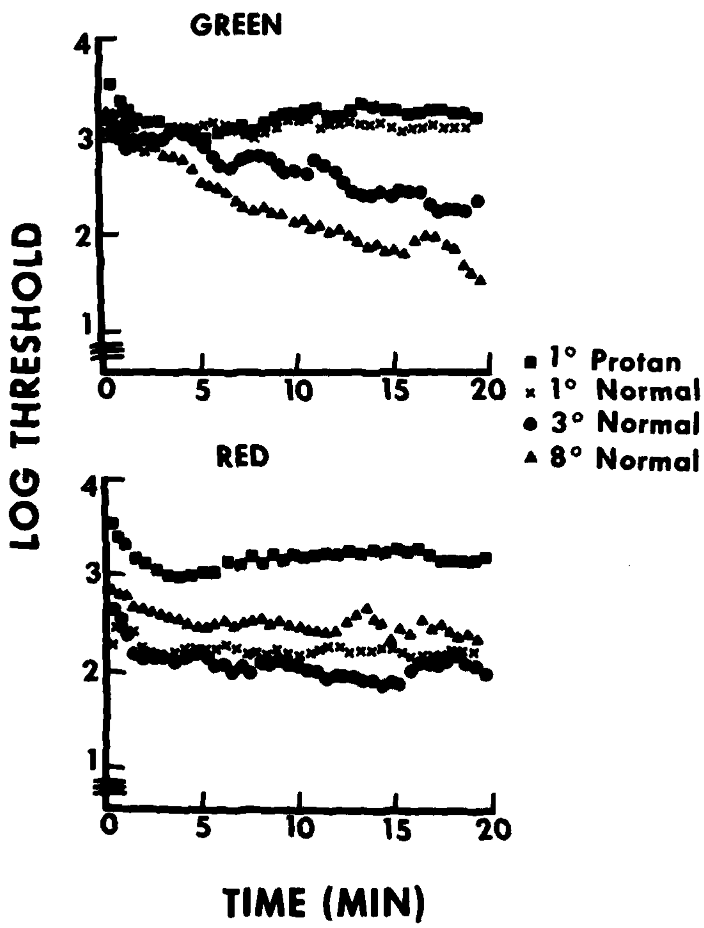

Figure 3. Data from one normal human volunteer measured at 8,3, and 1 degree eccentricity from fixation as well as data from one human protan (protanope) volunteer are presented. For the normal, threshold decreases in the red as eccentricity becomes more central and increases in the green with more central eccentricity. The protan at 1 degree is much higher on the red than the normal 1 degree function. In the green, the functions for normal and protan are identical.

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central, dark adaptation for the green LED becomes more shallow and an overall increase in threshold occurs. While the slope of the function for the red LED changes little as threshold measurement becomes more central, an overall increase in visual threshold for the red LED occurs. Data from the human protanope relative to the normal human at one degree eccentricity are considerably higher in threshold for the red LED than for the green LED.

DISCUSSION

In this paper, we have introduced a new dark adaptometer, the LAIR dark adaptometer, and data that validate its usage. Spectral dark adaptation measurements in the red region of the spectrum should be more rapid and shallow than measurements made in the green or blue-green region of the spectrum. Our data for large peripheral test fields with or without fixation support this finding (1,2).

Measurements of dark adaptation made within the central retina should reflect more cone function and less rod function. Anatomically, the density of cones increases towards the central retina while that of the rods decreases (6). Such is the case, as our red LED functions measured centrally are lower in threshold than comparable functions measured peripherally. Thus, increasing concentration of cone photoreceptors toward the central retina is reflected. Conversely, the increase in thresholds obtained for the green LED source reflects the general decrease in the concentration of rods as the central retina is approached.

Data obtained from individual subjects with peripheral retinal disease or congenital color vision deficiency involving long wavelength color discrimination also support the validation of this instrument. Traditional dark adaptometry made on the visual system of individuals having peripheral retinal disease always reflects greater loss in rod dark adaptation than cone dark adaptation. Our dark adaptation data for one person with peripheral retinal disease indicated more disruption in rod (green) adaptation measurements than in cone (red) dark adaptation measurements. Similarly, the one degree dark adaptation data of our single protanopic subject reflected a greater departure from long wavelength cone dark adaptation than shorter wavelength dark adaptation in normal and congenitally color blind human subjects (2).

The variability obtained for our spectral dark adaptation functions is quite similar to that obtained by Sloan (7) for conventional apparatus utilizing a white light test source. As in her study, 95% of the variability in our measurements of threshold equals

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about ±0.5 log units over the entire course of dark adaptation. Further comparison with the work of Sloan (7) is desirable, but comparison between a broadbanded white light test source and a spectral source is difficult. However, if her data are compared with our peripheral green LED function, as both reflect rod and cone function, the dynamic range over a comparable 20 minutes of dark adaptation is quite similar. Comparison with more recent human dark adaptation measurement made with green LED sources, where current rather than pulse modulation was used to control threshold detection, also yields a close agreement in overall dynamic range for the first 20 minutes of dark adaptation (8). Both these comparison studies measured dark adaptation out to 30 minutes and thus obtained about another 0.25 log units of adaptation. In several limited studies, we have obtained similar results, thereby suggesting that we are in fact measuring close to the full dynamic range obtained by Sloan (7) and others (8).

While the data presented here tend to support the usage of this adaptometer, its application to military night vision problems needs emphasis. Over the past two years, it has become increasingly obvious to us that the most routine screening of individuals for night vision military assignment can partial out individuals with severe night vision problems with underlying retinal disease etiology. While we have presented only a single case in this paper, we have made similar observations in many individuals, some of whom have been in critical positions during night vision military functions. The routine use of dark adaptometry testing to screen such individuals has obviously been greatly hampered by the complexity of the procedure and instrumentation typically associated with even the simplest dark adaptometry measurement. The LAIR adaptometer eliminates such complexity, as its computer-based format automatically plots and stores data and provides the basic options of measurement to the operator.

The associated problem of selection of those individuals that may adapt most rapidly and achieve the lowest final thresholds is a problem that can be more easily approached with an automated data storage instrument. The more complex problem of determining exactly what night vision functions are essential to overall night vision performance can best be assessed with the use of an instrument that will allow measurements of dark adaptation to be made in a varied format that offers maximum complexity of visual measurement with maximum flexibility in experimental design. The LAIR dark adaptometer will greatly aid the applied visual scientist to resolve the present problems of optimizing night vision performance. At the

same time, it will fill an important need for simple routine capability to measure rod and cone dark adaptation in the military population.

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